Open Access

J. Sustain. Econ. Dev., 2025, 3(1):69–81
ISSN (Online): 3005 -2513; ISSN (Print):3005-2505
DOI: https://doi.org/10.22194/JSD/25.45
https://societyfia.org/journal/JSD

Society for Innovative Agriculture

Assessing the Impact of Drinking Water Contamination on Stunting, Wasting and Underweight: Evidence from Children Under Five in Pakistan

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Contamination of drinking water with harmful bacteria such as Escherichia coli (*E. coli*) remains a serious concern for child health in low-resource settings, contributing to adverse physical health outcomes. This study examines the relationship between *E. coli* presence, environmental conditions, and children's health outcomes (stunting, wasting and underweight) in Pakistan, using a health production function model that conceptualizes health as a function of environmental, behavioral, and socioeconomic inputs. Drawing on data from 94,406 children under five from the Pakistan Multiple Indicator Cluster Survey (PMICS) Round 6, we applied logistic regression and propensity score matching (PSM) techniques to explore factors associated with stunting, underweight, and wasting. Logistic regression results indicate that higher temperatures are significantly associated with increased odds of underweight (OR: 1.428, $p < 0.001$) and stunting (OR: 1.109, $p < 0.001$). *E. coli* presence in drinking water is linked to an elevated risk of wasting (OR: 1.120, $p < 0.01$), and its interaction with high temperatures (>20°C) further exacerbates the likelihood of underweight (OR: 1.137, $p < 0.01$). WASH-related behaviors such as consistent handwashing with soap and media awareness are associated with reduced odds of all three children's health outcomes, while poor sanitation, floor dust exposure, and urban residence increase these risks. Socioeconomic indicators like higher maternal education and household wealth consistently show protective effects. PSM results reinforce these findings, showing significantly higher average treatment effects (ATTs) for underweight and wasting across all matching methods. For instance, kernel matching estimates an ATT of 0.030 for wasting and 0.013 for stunting, suggesting a notable association between *E. coli* contamination and poor anthropometric outcomes. While the associations are robust across methods, findings should be interpreted as correlational rather than causal. These results emphasize the importance of integrated policy responses that strengthen water sanitation, hygiene (WASH), and climate adaptation measures, while reducing socioeconomic disparities to stunting, wasting and underweight in Pakistan.

Keywords: Water Contamination, *E. coli*, Stunting, Wasting and Underweight, PMICS, WASH, Child Health, Health Production Function, Pakistan.

INTRODUCTION

Sustainable Development Goal (SDG) Target 6.1 aims to ensure universal and equitable access to safe and affordable drinking water for all by 2030. Yet, despite global progress, research indicates that unsafe drinking water continues to be the eighth leading cause of illness worldwide (Forouzanfar *et al.,* 2015). Recent studies indicate a troubling contradiction: even water from improved sources such as piped water, protected wells, and rainwater collection, which are assumed to be safe (World Health Organization (WHO) & UNICEF, 2015) may still be contaminated with fecal matter (Shaheed *et al.,* 2014; Bain *et al.,* 2014b). Globally, 1.8 billion people rely on a drinking water source suffering from fecal contamination (Bain *et al.,* 2014a). While directly measuring pathogens in faecal contamination is complex, fecal indicator bacteria, like *E. coli* or thermos tolerant coliform (TTC), are widely used to assess contamination levels (Bain *et al.,* 2014b;WHO, 2011). It's worth noting that the definition of improved water sources does not consistently guarantee microbial safety (Bain *et al.,* 2012).

Drinking water sources can contain various contaminants, including microorganisms like Escherichia Coli (*E. coli*) and Giardia, inorganic chemicals such as lead and arsenic, organic chemicals like atrazine and glyphosate, and dispahogens by-products like chloroform. Microbial contaminants pose a significant health risk, leading to water-borne diseases such

Khatoon, A. (2025). Assessing the Impact of Drinking Water Contamination on Child Malnutrition: Evidence from Children Under Five in Pakistan. *Journal of Sustainable and Economic Development, 3*(1): 69–81 .https://doi.org/10.22194/JSD/25.45
[Received 17 Jan 2025; Accepted 2 Apr 2025; Published 19 Jul 2025]

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as diarrhea and gastrointestinal illness (Arnone & Walling, 2007). Children, especially young ones who are under age 5 years, are particularly vulnerable to microbial contaminants due to their less developed immune systems compared to adults (Centers for Disease Control (CDC) & Prevention, 2010; Dietert, 2009; AM, 2001). This underscores the importance of ensuring safe drinking water to protect the health of the global population, with a particular focus on the susceptibility of children to water-borne diseases.

Globally, an estimated 180 million children under five suffer from stunted growth, resulting in approximately 3 million child deaths annually, predominantly occurring in low- and middle-income countries (Huey and Mehta, 2016; Gleason *et al.*, 2016). The causes of stunted growth are multifaceted and include factors such as diarrhoea, pneumonia, other infectious diseases, unsanitary conditions, food insecurity, and inadequate healthcare services. Stunted growth can lead to morbidities, including impaired cognitive development, reduced life expectancy, and an elevated risk of chronic diseases later in life. Four out of ten children under five in Pakistan experience stunted growth, with 17.7% suffering from wasting, 28.9% being underweight, and 9.5% overweight (UNICEF, 2019). The districts most affected are located in the southern regions of the country, specifically in the provinces of Baluchistan, Khyber Pakhtunkhwa, and Sindh, where the prevalence of stunting exceeds 50% (Cesare *et al.*, 2015). Childhood malnutrition is associated with an elevated risk of mortality from diarrhoea, pneumonia, and other infectious diseases, along with growth failure, cognitive delays, and reduced productivity (Caulfield *et al.*, 2004).

E. coli are bacteria commonly found in the environment, including water, food, and the intestines of humans and animals (CDC, 2010). In Pakistan, over 80% of the population drinks water contaminated with *E. coli* (Water Aid Pakistan, 2024), and studies show that water at the point of use is more likely to be contaminated than water collected from main sources (Hasan *et al.*, 2022). This contamination is often linked to poor management of household water resources, unimproved sanitation facilities, inadequate hand-washing practices, and issues with water storage (Uwimpuhwe *et al.*, 2014; Sharma & Bhattacharya, 2019). *E. coli* thrives at temperatures between 20 to 40 degrees Celsius (Kumar & Libchaber, 2013).

Unsafe drinking water, ranked as the eighth leading cause of global illness, continues to be a major health challenge (Forouzanfar *et al.*, 2015). *E. coli* is a primary pathogen in contaminated water, responsible for diarrheal diseases that disproportionately affect children under five (Hunter, 2003). Globally, over 700 children die daily from diarrhoea due to poor water, sanitation, and hygiene conditions (WHO, 2023). In Pakistan, open defecation impacts around 25 million people and contributes to 53,000 child deaths annually from diarrhoea (WHO, 2023). Diarrheal diseases also contribute to about 13.5% of global stunting cases (Checkley, 2008; Danaei et al., 2016), with 144 million children under five globally suffering from stunted growth, often linked to waterborne diseases (WHO, 2023).

In Pakistan, 40% of children under five suffer from stunting, and 28.9% are underweight (WHO, 2023). Stunting has a severe impact on early childhood development, cognitive and physical growth, educational outcomes, and long-term productivity. *E. coli*, in addition to causing diarrheal disease, is a common cause of neonatal meningitis, which affects new-borns and can lead to significant mortality and developmental issues (Liu, 2021).

Research indicates a complex relationship between temperature, *E. coli* levels in drinking water, and diarrheal disease risk. Higher temperatures and heavy precipitation were associated with increased *E. coli* levels in water sources (Powers *et al.*, 2022). However, *E. coli* survival in water decreased at higher temperatures, with longer persistence in cooler conditions (Sampson *et al.*, 2006). Pipe material and biofilm formation also influenced *E. coli* survival, with galvanized steel pipes showing the highest biofilm density (Silhan *et al.*, 2006). In household drinking water, a weak positive association was found between *E. coli* counts and diarrheal disease risk, including dysentery (Brown *et al.*, 2008). Interestingly, the presence of sand in water microcosms increased *E. coli* survival time regardless of temperature (Sampson *et al.*, 2006). These findings suggest that multiple factors, including temperature, precipitation, and water storage conditions, contribute to *E. coli* persistence and associated health risks in drinking water.

Based on the above research problem, the motivation of the proposed research is strongly aligned with Sustainable Development Goals (SDG) 6 and SDG 3. The widespread *E. coli* contamination in Pakistan's water supply, which leads to 53,000 diarrheal deaths annually, highlights the critical need for improved water management, supporting SDG 6 (ensuring availability and sustainable management of water and sanitation for all). Furthermore, the significant impact of *E. coli*-related diseases on stunting and early childhood development contributes to a human capital crisis. Tackling these health challenges aligns with SDG 3 (ensuring healthy lives and promoting well-being for all) by addressing child mortality and enhancing overall health outcomes and SDG4.2.1 focusing on early childhood development.

This study aims to examine the impact of Escherichia coli (*E. coli*) contamination in drinking water on the physical health outcomes of children under five in Pakistan. The first 1,000 days of life are critical for both cognitive and physical development, and exposure to unsafe drinking water during this period can have lasting effects. Specifically, this research addresses two core questions: (1) How does *E. coli* contamination in household drinking water influence child children's health outcomes such as stunting, wasting, and underweight? and (2) To what extent do WASH (Water, Sanitation, and Hygiene) behaviors and water treatment

practices mitigate these effects? Using data from the Pakistan Multiple Indicator Cluster Survey (PMICS) Round 6, covering the provinces of Sindh, Punjab, Khyber Pakhtunkhwa (KP), and Balochistan, the study applies a causal inference approach propensity score matching (PSM) to compare outcomes between children exposed to *E. coli*-contaminated water and those who are not.

PSM is particularly appropriate for this observational study as it helps reduce selection bias by creating a balanced comparison between treated and untreated groups based on observed covariates, thus approximating the conditions of a randomized controlled trial (Rosenbaum & Rubin, 1983). By matching children from households with *E. coli* exposure (the treatment group) to those without it (the control group), we can isolate the causal effect of *E. coli* contamination on children's health (stunting, wasting and underweight) outcomes while controlling for confounding variables such as socioeconomic status, sanitation practices, and household characteristics (Austin, 2011). This approach has been widely used in health and social science research to mitigate the limitations of non-randomized observational data, ensuring more robust and reliable causal inferences (Stuart, 2010; Imbens, 2004).

Despite the well-documented health burden of waterborne diseases in Pakistan, limited empirical research has explored the combined effects of microbial contamination specifically *E. coli* and environmental stressors such as temperature on children's health (stunting, wasting and underweight) at the national level. Most existing studies focus on either biological or environmental determinants in isolation, often using localized or clinical datasets. This study fills a critical gap by integrating nationally representative PMICS data to assess the compounded risk of *E. coli* exposure and poor WASH practices on stunting, wasting, and underweight among children under five. By applying a causal inference approach through propensity score matching (PSM), this research contributes novel evidence on how microbial water quality and mitigating behaviors interact to influence early childhood health outcomes, thus directly informing SDG targets 3.2, 4.2.1, and 6.1.

MATERIALS AND METHODS

***Data Source: Multiple Indicator Cluster Survey (MICS)*:** The MICS, a survey initiative backed by UNICEF, stands as a prominent global data source, spanning 120+ countries and conducting 300+ surveys in the last 25 years. Governed by national bodies with UNICEF's technical support throughout, these cross-sectional surveys utilize a multi-stage stratified sampling method. Enumeration areas from the national census are randomly chosen, with subsequent random selection of household clusters (usually 20–25) within these areas. Each household possesses a known selection probability, facilitating the generation of national estimates. Stratification, considering factors like urban/rural and geographic regions, ensures adequate subnational sample sizes.

***Survey Design and Sample*:** Covering diverse topics such as household assets, water and sanitation, child labor, health, and nutrition, MICS employs same-sex interviewers within interview teams, along with a van driver, supervisor, and measurer for anthropometric data. Conducted in rounds, countries typically undergo surveys once every 3–5 years, maintaining consistency across survey implementation. We will use Pakistan dataset of MICS. In Punjab during MICS Round 6 in the survey year 2017-18, data was gathered from a total of 53,840 households, with 15,980 in rural areas and 37,860 in urban areas, distributed across 36 districts. In Sindh during MICS Round 6 in 2018-19, a total of 20,540 households were surveyed, with 10,740 in urban areas and 9,800 in rural areas, across 29 districts. In Baluchistan during MICS Round 6 in 2019-20, data was collected from 21,380 households, with 4,780 in urban areas and 16,600 in rural areas, covering 32 districts. Lastly, in Khyber Pakhtunkhwa (KP) during MICS Round 6 in 2019, a total of 23,740 households were surveyed, with 3,160 in urban areas and 20,580 in rural areas, distributed across 32 districts. After cleaning the dataset and applying relevant inclusion criteria, the final analytical sample consists of 94,406 children under five.

***Water Quality Testing Procedure*:** Water quality test implemented in a subset of households (typically 3 to 5) within each cluster, this selective approach aims to minimize costs and workload, anticipating marginal gains due to intra-cluster correlation. For households chosen for water quality testing, the interviewer seeks permission to collect drinking water samples, requesting a "glass of drinking water" (Point of use - PoU) and locating the source of drinking water (Point of consumption - PoS) to collect a sample. Analysis of the two samples explores quality differences between PoS and PoU (Shields et al. 2015; Wright et al. 2004). The water quality testing questionnaire documents test results and includes inquiries about the source of the drinking water glass and observations on water storage practices. The field team member responsible for water quality testing may vary across surveys based on task distribution, with the measurer, typically handling anthropometry, often conducting the water quality test.

Specifically, 100 ml water samples were collected at the household level and filtered through a membrane to retain any *E. coli*. The membranes were incubated using Compact Dry Plates, which contain a growth medium with a chemical (X-Gluc) that turns *E. coli* colonies blue/green. After 24 to 48 hours, colonies were visually counted, and only blue/green colonies were classified as *E. coli*, following standardized microbiological procedures outlined in the PMICS field protocols. For analytical purposes, the presence of *E. coli* was recorded as a binary variable, coded as 1 if *E. coli* was

detected in the household drinking water sample, and 0 otherwise.

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This study builds on (Grossman, 1972) health production function framework to investigate children's physical health outcomes, focusing on stunting, underweight, and wasting as indicators. Grossman's model views health as a productive stock that households can influence through resource allocation and behaviour. Expanding this, (Freeman, 2014) emphasizes the role of environmental exposures and household responses in shaping health outcomes, particularly for vulnerable groups like young children. Consider the case where a household has 'children under five and their health status may have affected by the household *E. coli* contamination in drinking water point of use and other factors. A child's health is associated with the contamination level is described by the dose response function. The econometric model of dose response function is specified as follows:

$$H = H(E, A, X, \mu) \quad (1)$$

Where the outcome variable H is the three different children's health (stunting, wasting and underweight) in a child with H=1 if the child has stunting, otherwise 0, H=1 if child has underweight, otherwise 0 and H=1 if child has wasting, otherwise 0. These will be three different model regress separately. The status of physical health in child is a function of environmental exposure that is *E. coli* contamination present in household, averring activities A undertaken by the household, and a set of other exogenous variables, denoted by vector X including child characteristics, household characteristics and mother characteristics. The error component μ includes the location specific component u and the random error term e. H(.) is a function taking on values strictly between 0 and 1. Below we describe the variables and discuss how the outcome variable can be affected by the explanatory variables given in equation (1).

***Health outcome of child*:** In equation (1) each outcome variable (stunting, wasting, and underweight) is dichotomous: taking the value of 1 if the child meets the criteria (e.g., stunted, wasted, or underweight) and 0 otherwise. This study analyses stunting, wasting, and underweight among children under five, using data from all four provinces of Pakistan: Punjab 2017-18, Sindh 2018-19, Khyber Pakhtunkhwa 2019, and Balochistan 2019-20. Children in this age group are categorized into five age ranges for detailed analysis: 0–12 months, 13–24 months, 25–36 months, 37–48 months, and 49–59 months. Data from the Pakistan Multiple Indicators Cluster Survey (PMICS), which includes measurements of children's weights (kg) and heights (cm) across these provinces, was compiled and analysed. In this study, the analysis focuses on children under five to assess the prevalence and factors associated with stunting, wasting, and underweight. Stunting is identified based on WHO child growth standards, where a child is considered stunted if their height-for-age Z score is less than minus two standard deviations −2 SD, a child is classified as wasted if their weight-for-height z-score (WHZ) is less than minus two standard deviations −2 SD, a child is classified as underweight if their weight-for-age z-score (WAZ) is less than minus two standard deviations −2 SD (UNO; United Nations Children Fund, 2009).

***Environmental Exposures*:** The *E. coli* variable in this study is measured at the Point of Use (PoU) to capture the actual quality of drinking water as it is consumed by household members. This approach directly reflects the potential exposure to *E. coli* contamination at the point where water is most likely ingested, providing a more accurate assessment of health risk compared to sampling only at the source. The MICS dataset categorizes *E. coli* contamination into four risk levels: low risk if *E. coli* is less than 1 per 100 ml, moderate risk if *E. coli* is between 1 to 10 per 100 ml, high risk if *E. coli* is between 11 to 100 per 100 ml, and very high risk if *E. coli* is greater than 100 per 100 ml. For the purposes of this study, the *E. coli* variable was converted into a binary form, where low and moderate risk levels were coded as 0, and high and very high risk levels were coded as 1.

The temperature variable was constructed using daily maximum temperature data. Districts were analysed to identify the cumulative number of days with maximum temperatures exceeding 20°C within a defined time period. For Punjab, the temperature data spanned from January 1, 2017, to December 31, 2018, corresponding with the MICS 2017-18 dataset. For Sindh, data covered January 1, 2018, to December 31, 2019, aligning with the MICS 2018-19 dataset. For Khyber Pakhtunkhwa (KPK), the period was January 1, 2019, to December 31, 2019, to match the MICS 2019 data. For Balochistan, the time frame extended from January 1, 2019, to December 31, 2020, reflecting the MICS 2019-20 data. Districts with more than 600 days of temperatures above 20°C during these periods were marked to account for long-term exposure to high temperatures.

The interaction term *E. coli* × Temperature is included because existing literature shows that *E. coli* levels tend to increase as temperatures rise. Higher temperatures, particularly above 20°C, create conditions that promote bacterial growth, thereby intensifying contamination risks. By incorporating this interaction term, the study aims to better capture how elevated temperatures amplify health risks associated with *E. coli* exposure in drinking water, aligning with research findings that temperature and bacterial proliferation are closely linked.

***Averting Activities*:** Averting activities are taken to reduce the exposure to *E. coli* contamination in drinking water and thus affect the health outcomes (Freeman et al. 2014). In this study, hygiene, sanitation, media awareness, and floor dust are considered key averting activities. Hygiene is captured by a

survey question asking whether the household washes hands with soap. Households that report washing hands with soap are coded as 1, and those that do not are coded as 0. Improved hygiene practices, such as handwashing with soap, can reduce the transmission of waterborne pathogens like *E. coli*, thus lowering the risk of gastrointestinal diseases and other infections. By reducing the likelihood of contamination through improper hand hygiene, this averting behavior helps safeguard the health of children, especially in environments where water quality may be compromised. Improved sanitation facilities are another key averting activity. We classify households with access to improved sanitation facilities as 1, and those without as 0. Access to improved sanitation reduces environmental contamination by ensuring the proper disposal of human waste, which can otherwise contaminate water sources. This practice significantly decreases the risk of exposure to harmful pathogens, including *E. coli*, which can adversely affect children's health, causing illnesses such as diarrhea and stunting. Media awareness, measured through the mother's engagement with information sources, is another important averting activity. We use three variables from the women survey to gauge media exposure: whether the mother reads the newspaper, listens to the radio, and watches television. If the mother engages with all three media forms in the past week, the household is coded as 1; otherwise, it is coded as 0. Media exposure plays a vital role in spreading knowledge about health risks and protective behaviors, such as improving sanitation and hygiene practices. Increased media awareness can influence behavior, encouraging households to adopt measures that reduce *E. coli* contamination and its health impacts on children. Floor dust is also considered an averting activity. If the household floor is reported to have dust, it is coded as 1; otherwise, it is coded as 0. This variable is particularly important because young children, especially those in the crawling stage, often put their hands or toys in their mouths after coming into contact with dust. This behavior can lead to the ingestion of soil-transmitted helminths (STH) and other harmful pathogens, which can cause bacterial infections and increase the risk of diarrhea. By reducing dust levels on household floors, this averting activity helps minimize the risk of exposure to such harmful bacteria, thus promoting better health outcomes for children.

***Child Characteristics*:** In child characteristics, we have considered child sex, age, and the prevalence of diarrhea as key factors. Age is an important predictor of physical health outcomes like children's health, as children's immune systems are more vulnerable to infections. For detailed analysis, children are categorized into five age groups: 0–12 months (coded as 1), 13–24 months (coded as 2), 25–36 months (coded as 3), 37–48 months (coded as 4), and 49–59 months (coded as 5). Child sex is also a significant factor, with studies showing that boys are generally more susceptible to stunting, wasting, and underweight than girls. In our dataset, boys are coded as 1 and girls as 0. Diarrhea prevalence is another important variable, as it directly influences a child's health and nutritional status. If a child experienced diarrhea in the last two weeks, it is coded as 1; otherwise, it is coded as 0. Diarrhea remains a leading cause of children's health (stunting, wasting and underweight), especially in children, and its prevalence is a significant contributor to both short-term and long-term health outcomes. The high frequency of diarrhea episodes can exacerbate children's health by reducing nutrient absorption and increasing the risk of dehydration and infection.

***Household characteristics*:** In the household characteristics, we have considered household head education, wealth quantile, and area of residence as key variables. The level of education of the household head plays a crucial role in determining the socioeconomic status and access to resources within the household, which in turn impacts child health outcomes. We categorize the household head's education as binary: if the household head has no primary education, it is coded as 0, and if they have completed secondary education, it is coded as 1. This categorization helps to assess the impact of parental education on child nutrition and health, as educated parents are more likely to adopt better health practices and seek medical care when needed. Wealth is a critical determinant of access to nutrition, healthcare, and overall well-being. We categorize wealth into three quantiles: poor, middle, and rich. Poor is coded as 1, middle as 2, and rich as 3. This classification allows for the analysis of how economic status influences children's health (stunting, wasting and underweight) outcomes, as wealthier households typically have better access to nutritious food, healthcare, and sanitation facilities. The area of residence is an important variable, as it often determines access to infrastructure, healthcare, and sanitation services. Households in urban areas tend to have better access to these services than those in rural areas. Area of residence is coded as 1 for urban and 0 for rural. This distinction helps to capture the impact of rural vs. urban living conditions on children's health (stunting, wasting and underweight), as rural areas often face challenges such as limited access to healthcare, clean water, and sanitation facilities.

***Mother characteristics*:** For mother characteristics, we have taken mother's education as the only variable. Maternal education is a key determinant of child health, as educated mothers are generally better equipped to make informed decisions about nutrition, healthcare, and sanitation. Educated mothers are more likely to engage in averting activities as they are more aware of children's health and the risk associated with it. We categorize maternal education as binary: if the mother has no primary education, it is coded as 0, and if she has completed secondary education, it is coded as 1. This variable helps to assess the impact of maternal education on the health and nutrition of children, as educated mothers are more likely to implement preventive health measures, seek

timely medical attention, and provide better nutrition for their children.

We control for unobserved variables such as access to and use of health services, other environmental factors and location-specific characteristics by incorporating fixed effects for geographic locations. For this, we apply the fixed effects at the level of primary sampling units (PSUs), as described in the data section.

The model outlined in Equation (1) is estimated using a logistic regression framework with fixed effects, specifically through a conditional logit fixed-effects model. This method helps eliminate potential omitted variable bias from unobserved factors that could correlate with the included explanatory variables. To ensure consistent coefficient estimation, we use the maximum likelihood estimation (MLE) technique due to its suitability for large samples. Additionally, we adjust for the survey design and sample weights in the estimation process to mitigate any influence from over or under sampling and non-response, ensuring the sample's representativeness for the broader population.

Ordinary Least Squares (OLS) is a common and straightforward method for analysing associations between variables; however, it may not adequately address the influence of confounding variables, limiting its capacity to identify causal relationships. To address this, propensity score matching (PSM) is often utilized in impact evaluation studies. PSM helps mitigate self-selection bias by comparing outcomes between a treated group (e.g., children exposed to *E. coli* contamination) and a control group (children without such exposure). The propensity score, defined by (Rosenbaum & Rubin,1983) as the probability of treatment assignment based on observed characteristics, is used to create a comparable control group.

Matching methods control for variables that could influence treatment decisions and outcomes. Covariates such as household and child characteristics are included to reduce bias and improve the reliability of causal inferences related to stunting, wasting, and underweight among children.

The average treatment effect on the treated (ATT) measures differences in mean outcomes between treated and control groups. To address potential matching quality issues, various PSM methods are applied, including:

1. **Nearest Neighbor Matching**: Pairs each treated child with the control child having the closest propensity score.
2. **Radius Matching**: Uses caliper bands to allow for a range within which matches are accepted, improving match quality.
3. **Kernel and Local Linear Regression (LLR)**: A nonparametric method that calculates a weighted average of control cases for matching.

Each method has specific advantages and limitations. Applying multiple PSM techniques ensures the robustness of results when assessing the impact of *E. coli* contamination on child health outcomes.

RESULTS AND DISCUSSION

In this section, we present results from logistic regression and propensity score matching (PSM) analyses that evaluate relationships between environmental, sanitation, and socioeconomic factors and children's health (stunting, wasting and underweight). Logistic regression quantifies odds ratios to assess the impact of variables like temperature, *E. coli* presence, and socioeconomic factors on children's health (stunting, wasting and underweight). Additionally, PSM techniques, including nearest neighbor, radius, kernel, and stratification matching, were applied to account for selection bias and ensure robust comparisons between children exposed to *E. coli* contaminated drinking water and those unexposed. By combining these methodologies, we aim to offer a comprehensive analysis of environmental and household-level factors contributing to stunting, wasting and underweight outcomes, providing insights crucial to addressing children's health. Table 1 summarizes descriptive statistics of sample characteristics (child age, household income, maternal education, sanitation access), setting context for interpreting stunting, wasting and underweight indicators. Table 2 presents logistic regression results, showing significant odds ratios for factors like *E. coli* presence in drinking water, temperature, and socioeconomic status on risks of stunting, underweight, and wasting. Finally, Table 3 highlights PSM results, revealing the substantial effect of *E. coli* exposure on stunting, wasting and underweight while adjusting for potential confounders.

The descriptive statistics provide an overview of the sample characteristics, focusing on various factors related to child health and environmental conditions. The data reveals that 37.87% of children are stunted, 26.45% are underweight, and 10.06% are experiencing wasting, highlighting significant levels of stunting, wasting and underweight among children under five. In terms of environmental factors, the majority of observations (67.31%) report daily maximum temperatures exceeding 20°C. Additionally, *E. coli* contamination is prevalent in household drinking water, affecting 90.79% of the sample. When considering the interaction between *E. coli* presence and high temperatures, only 5.27% of household's experience both conditions, while 94.73% do not. Household characteristics show that 53.88% of homes have dusty floors, indicating poor indoor environmental quality. A significant portion of the sample resides in rural areas (75.24%), while only 24.76% live in urban settings. Mass media awareness is present in 40.74% of households, and 78.03% of the sample practices hand washing with soap, suggesting varying levels of health knowledge and practices.

Regarding demographic factors, the sample is almost evenly split between boy (51.56%) and girl (48.44%) children. The age distribution of children under five is fairly balanced, with each age group contributing between 18% and 21% to the total sample. A large proportion of mothers (76.08%) have no

Table 1. Descriptive Statistics

Variable Name	Variable Categories	Percent	No. of observation
Child' Stunting			
	No	62.13	65280
	Yes	37.87	39,790
Child's Underweight			
	No	73.55	77277
	Yes	26.45	27793
Child's Wasting			
	No	89.94	94498
	Yes	10.06	10571
Temperature greater than 20 degree centigrade			
	Number of Daily maximum Temperature less than 600 frequency	32.69	34345
	Number of Daily maximum Temperature greater than 600 frequency	67.31	70725
E.coli in Household Drinking water			
	E.coli in Drinking water Present (Yes)	90.79	95393
	E.coli in Drinking water Absent (No)	9.21	9677
Interaction E.coli and Temperature			
	No	94.73	90537
	Yes	5.27	5533
Floor with Dust			
	No	46.12	48461
	Yes	53.88	56609
Improved Sanitation			
	No	31.10	32678
	Yes	68.90	72392
Mass Media Awareness			
	No	59.26	62088
	Yes	40.74	42681
Hand Washing Practice With Soap			
	No	21.97	23082
	Yes	78.03	81988
Sex of Child			
	Male	51.56	54170
	Female	48.44	50900
Age Category			
	0-12 Months	21.07	20138
	13-24 Months	18.01	17207
	25-36 Months	20.06	19171
	37-48 Months	21.62	20664
	49-59 Months	19.24	18387
Diarrhoea Prevalence in last two weeks			
	No	82.71	86090
	Yes	17.29	18001
Mother Education			
	No Primary Education (No)	76.08	79823
	Secondary Education (Yes)	23.92	25090
Wealth Quantile			
	Poor	45.65	47962
	Middle	28.91	30376
	Rich	25.44	26731
Education of Household Head			
	No Primary Education (No)	64.81	68078
	Secondary Education (Yes)	35.19	36962
Area of Residence			
	Urban	24.76	26015
	Rural	75.24	79055

primary education, while 23.92% have completed secondary education. Socioeconomic status is reflected in the wealth quantiles, with 45.65% of households classified as poor, 28.91% as middle-income, and 25.44% as rich.

Education levels of household heads reveal that 64.81% have not completed primary education, while 35.19% have secondary education. Improved sanitation is available to 68.90% of the households, whereas 31.10% lack access to

Table 2. Logistic Regression Result Odd Ratio .

	Stunting ***Model 1***	**Underweight** ***Model 2***	**Wasting** ***Model 3***
Temperature			
No	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Yes	1.109*** [1.073,1.147]	1.428*** [1.376,1.481]	1.023 [0.971,1.077]
E.coli			
E.coli in Drinking water Absent	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
E.coli in Drinking water Present	0.965 [0.896,1.039]	1.034 [0.952,1.123]	1.120** [1.002,1.251]
Interaction of E.coli with Temperature > 20 degree centigrade			
No	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Yes	1.096* [0.996,1.207]	1.137** [1.025,1.261]	0.988 [0.854,1.141]
Floor with Dust			
No	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Yes	1.185*** [1.141,1.230]	1.271*** [1.220,1.325]	1.207*** [1.136,1.282]
Area of Residency			
Rural	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Urban	1.171*** [1.128,1.215]	1.211*** [1.163,1.262]	1.205*** [1.137,1.276]
Mass Media Awareness			
No	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Yes	0.880*** [0.852,0.909]	0.863*** [0.833,0.894]	0.907*** [0.861,0.955]
Hand Washing Practice with Soap			
No	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Yes	0.845*** [0.816,0.874]	0.756*** [0.729,0.783]	0.791*** [0.750,0.833]
Sex of Child			
Girl	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Boy	0.966** [0.940,0.992]	0.820*** [0.796,0.845]	0.781*** [0.748,0.816]
Age Category of children under five			
0-12 Months	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
13-24 Months	1.971*** [1.883,2.063]	0.985 [0.940,1.033]	0.770*** [0.725,0.818]
25-36 Months	2.583*** [2.471,2.700]	1.139*** [1.088,1.191]	0.599*** [0.563,0.638]
37-48 Months	2.491*** [2.385,2.602]	0.944** [0.902,0.988]	0.430*** [0.402,0.459]
49-59 Months	1.865*** [1.783,1.951]	0.777*** [0.741,0.815]	0.405*** [0.378,0.435]
Mother Education			
Primary	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Secondary	0.639*** [0.613,0.665]	0.688*** [0.657,0.720]	0.871*** [0.816,0.929]
Wealth Quantiles			
Poor	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Middle	0.890*** [0.857,0.925]	0.942*** [0.904,0.981]	1.013 [0.954,1.075]
Rich	0.762*** [0.722,0.803]	0.821*** [0.774,0.871]	0.960 [0.884,1.043]
Household Head Education			
Primary	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Secondary	0.875*** [0.848,0.903]	0.888*** [0.858,0.920]	0.973 [0.925,1.023]
Improved Sanitation			
No	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Yes	0.843*** [0.815,0.871]	0.799*** [0.772,0.828]	0.805*** [0.764,0.847]
Diarrhoea Prevalence in last two weeks			
No	1.000 [1.000,1.000]	1.000 [1.000,1.000]	1.000 [1.000,1.000]
Yes	1.156*** [1.115,1.198]	1.110*** [1.068,1.154]	1.050* [0.993,1.109]
Observation	94406	94406	94405
Probability> Chi^2	0.0000	0.0000	0.0000
Likelihood Ratio (LR) chi-square	5333.88	3608.16	1681.84

Exponentiated coefficients; 95% confidence intervals in brackets; * p<0.1, ** p<0.05, *** p<0.01

such facilities. Finally, the prevalence of diarrhoea in the last two weeks is reported in 17.29% of the children, indicating ongoing health challenges within the sample population.

The results of the logistic regression models show significant relationships between various socio-environmental factors and stunting, underweight, and wasting among children under five. Higher temperatures are positively associated with an increased risk of stunting and underweight, indicating that environmental stress due to heat could exacerbate nutritional deficiencies in children. This is consistent with findings by

(Checkley *et al.*, 2000), who suggest that higher temperatures can contribute to diarrheal diseases, which in turn affect nutritional status.

E. coli contamination in drinking water is associated with a higher risk of wasting, though its relationship with stunting and underweight is not statistically significant. The presence of *E. coli* likely indicates poor water quality and sanitation, which can lead to infections and hinder nutrient absorption, thereby increasing wasting. This finding aligns with research by (*Guerrant et al.*, 2008), who emphasize the role of enteric infections in the etiology of malnutrition. The interaction between *E. coli* presence and temperatures above 20°C shows a significant increase in the odds of stunting and underweight, further highlighting the compounded risk of poor water quality and environmental stress on child nutrition. This suggests that interventions should focus on improving water safety, particularly in warmer regions.

Living in households with dusty floors significantly increases the likelihood of all three children's health outcomes. Dusty environments may reflect poor hygiene and increased exposure to pathogens, which can impair child growth. Similarly, urban residency is associated with higher odds of stunting, underweight, and wasting, possibly due to urban overcrowding, pollution, and inadequate living conditions, as discussed by (Fotso, 2007).

Mass media awareness appears to be protective, significantly reducing the odds of stunting, underweight, and wasting. This effect could be due to increased health knowledge and practices promoted through media channels, which help in better child care and feeding practices. Hand washing practices with soap also show a protective effect, significantly lowering the risk of all three children's health outcomes. This aligns with the findings of (Curtis & Cairncross, 2003), who emphasize the importance of hygiene in preventing infections and improving nutritional status.

The analysis also reveals that male children are slightly less likely to experience stunting, underweight, and wasting, indicating potential gender differences in nutritional vulnerability. Older children are at higher risk of stunting, particularly in the 25-36 months' age group, likely due to weaning and increased exposure to infections, as noted by (Dewey & Adu-Afarwuah, 2008). However, the odds of underweight and wasting decrease with age, reflecting potential recovery in nutritional status as children grow older.

Maternal education, particularly secondary education, significantly reduces the odds of stunting, underweight, and wasting. Educated mothers are more likely to adopt better childcare and feeding practices, leading to improved child nutrition. This finding is consistent with the work of (Caldwell, 1979), who highlighted the role of maternal education in child health outcomes. Similarly, higher household wealth is associated with lower odds of stunting and underweight, indicating that better economic resources contribute to improved nutrition through access to better food, healthcare, and living conditions.

The education level of the household head also plays a role, with secondary education reducing the odds of stunting and underweight, though its impact on wasting is not significant. Improved sanitation is strongly associated with lower odds of all three children's health outcomes, underscoring the importance of adequate sanitation in preventing infections and promoting healthy growth. Lastly, recent diarrhoea episodes significantly increase the odds of stunting and underweight, reflecting the detrimental impact of infections on child growth and nutrition, as discussed by (Black *et al.*, 2008). These findings suggest that improving environmental conditions, sanitation, and parental education are critical for reducing stunting, wasting and underweight among children in Pakistan.

Table 3. ATT of *E. coli* in Household Drinking for anthropometry measures.

Matching technique	Stunting ATT	Underweight ATT	Wasting ATT
Nearest neighbour matching	0.003	0.032***	0.027***
	(0.009)	(0.147)	(0.006)
Radius matching	0.032***	0.047***	0.031***
	(0.079)	(0.005)	(0.004)
Kernel matching	0.013***	-1.535***	0.030***
	(0.003)	(0.035)	(0.004)
Stratification matching	0.009	0.032***	0.029***
	(0.009)	(0.008)	(0.005)

The standard errors are provided in parentheses. Significance levels are denoted by ***, **, and *, corresponding to 1%, 5%, and 10%, respectively.

The Average Treatment Effect on the Treated (ATT) in Table 3 evaluates the impact of *E. coli* contamination in household drinking water on anthropometric measures specifically, stunting, underweight, and wasting in children under five. Multiple matching techniques, including nearest neighbor, radius, kernel, and stratification matching, were used to increase the robustness of the findings. For stunting, results vary across methods, with radius and kernel matching indicating a significant increase in stunting rates linked to *E. coli* exposure. This suggests that children in households with *E. coli*-contaminated water may have a higher likelihood of stunting, likely due to nutrient absorption issues from recurring infections (Joseph *et al.*, 2019 and Feliyanti *et al.*, 2024;). The results for underweight are significant across all matching methods, showing a strong association between *E. coli* exposure and an increased likelihood of children being underweight. This finding aligns with the hypothesis that infections from contaminated water can impede children's weight gain by redirecting nutrients toward immune responses rather than growth. Additionally, wasting shows a significant positive ATT across all matching techniques,

indicating that *E. coli* contamination is associated with a higher risk of wasting. This consistent outcome across various methods suggests that *E. coli* contamination contributes to both acute and chronic nutritional deficits, likely because of prolonged exposure to pathogens. These findings affirm that *E. coli* contamination in drinking water negatively affects children's growth and nutrition, especially for wasting and underweight conditions, underscoring the importance of securing safe drinking water.

Conclusion and Policy Recommendations**:** *E. coli* contamination in drinking water has a measurable, adverse impact on children's health, particularly regarding wasting and underweight outcomes. This study demonstrates the urgent need for improved water quality management to reduce microbial contamination and promote child health, especially in regions where stunting, wasting, and underweight are prevalent among children. The findings underscore that ensuring microbial safety in drinking water is critical to addressing stunting, wasting and underweight and safeguarding the health and development of young children.

To address these concerns, several policy actions are recommended. First, there is a need to strengthen water quality monitoring and standards, with regular testing of water sources for fecal contaminants such as *E. coli*. This would allow for early detection and intervention, especially at the household level, to ensure safer drinking water. Second, promoting household water treatment methods, including boiling, filtering, or treating water before consumption, can reduce exposure to *E. coli* significantly. Educational campaigns to inform households about these methods, combined with subsidies for tools like water filters, can encourage widespread adoption. Third, public health education programs focused on sanitation and hygiene practices, particularly in rural and underserved urban areas, are essential to mitigate environmental contamination and reduce the spread of waterborne diseases. Fourth, targeted interventions in high-risk areas—those with high temperatures, dusty environments, and limited sanitation access—should be prioritized, with clean water initiatives and sanitation infrastructure development to reduce contamination and promote health. Finally, expanding access to health education campaigns via mass media can increase public awareness of hygiene practices, water treatment, and sanitation. These targeted actions will allow policymakers to address the health risks associated with *E. coli* contamination effectively, improve child health outcomes, and support Sustainable Development Goals related to clean water, sanitation, and overall child health.

Author Contributions**:** Aysha Khatoon The author solely conceived, designed, conducted the research, analysed the data, and wrote the manuscript.

Conflict of Interest**:** The authors declare no conflict of interest.

Funding**:** No funding was received for this research.

Ethical Statement**:** Not applicable.

Availability of Data and Materials**:** All data analysed during this study is publicly available and has been referenced within the article.

Acknowledgment**:** The authors extend gratitude to UNICEF and the Pakistan Bureau of Statistics for making the PMICS data available, and to academic mentors who provided guidance during the research.

Informed Consent**:** Not applicable.

Consent to Participate**:** Not applicable.

Consent for Publication**:** All authors have given their consent for the publication of this research in the Journal of Sustainable and Economic Development (JSED).

(SDGs) Addressed**: SDG 3**: Ensure healthy lives and promote well-being for all at all ages.

SDG 6: Ensure availability and sustainable management of water and sanitation for all.

Policy referred**:** WASH (Water, Sanitation, and Hygiene) Policy Reform; Climate-Health Adaptation Policies; Targeted Investment in High-Risk Regions;Climate-Health Adaptation Policies.

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